HERMES-III PROTOTYPE CAVITY TESTS*

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Abstract

The Hermes-III accelerator has twenty 1-MV, inductively isolated cavities connected in series through a high voltage, magnetically insulated transmission line (MITL) to produce a 20-MV, 800-kA pulse that drives a bremsstrahlung diode. Each cavity is 4 m in diameter and weighs nearly 8000 kg when filled with its insulating transformer oil. Cores of pre-annealed Metglas 2605CO are used to inductively isolate the cavities. Azimuthal transmission lines mix inputs from four pulse-forming lines; this reduces the effect of pulse-forming line jitter on the cavity output pulse. A single, prototype cavity has been tested on the System Test Facility (STF). The test results and comparisons with design specifications and circuit simulations are presented.

Introduction

Hermes III is being constructed to provide a radiation source for testing vulnerability, hardening, and survivability of future U.S. weapon systems. The goals for Hermes III are to produce outputs of 5×10^{12} rad/s and 2×10^{20} rad/s^2 over a 500 cm^2 area with variations less than a factor of 2 and with a radiation pulse width of less than 20-ns FWHM. Variations of less than a factor of four in dose rate are required within a volume that extends 15 cm away from this front surface area. To meet these goals and requirements, Hermes III has been designed to deliver a 20-MV, 800-kA, 40-ns FWHM electrical pulse to a bremsstrahlung diode.

An overview of the Hermes-III accelerator is given in another paper in this proceedings,[1] so only a brief description of the accelerator will be presented here. The Hermes-III accelerator uses ten, parallel pulse-forming systems to drive twenty, inductively isolated acceleration cavities. Each system has a 2.4-MV, 156-kJ Marx generator that pulse charges two, water-dielectric, intermediate storage capacitors in ~1 μs. Each of these capacitors pulse charges four, water-insulated, 5-Ω pulse-forming lines (PFL) through a laser-triggered, SF_6-insulated gas switch in ~200 ns. The nominal output from the PFLs is a 1.1-MV, 40-ns FWHM pulse. These output pulses serve as the input to the inductively isolated cavities. The twenty cavities are connected in series and form the outer conductor of a magnetically insulated transmission line (MITL) adder[2] that adds the individual cavity outputs.

Cavity

The Hermes-III cavities serve two functions. The first is to combine the output pulses from four separate pulse-forming lines in parallel and deliver the summed output to the MITL adder in the interior of the cavity. The second is to provide inductive isolation so that the cavity output pulses may be added in series while maintaining the exterior of the cavities at ground potential. The initial design of the prototype cavity tested on the Subsystem Test Facility (STF) was performed by Pulsed Sciences, Inc.[3] (PSI) under contract from Sandia National Laboratories.

Given four 5-Ω inputs with 10-ns rise times (10% to 90%) and a rms jitter of 4.5 ns, the cavity output pulse was specified to have a 10% to 90% rise time less than 19 ns. The peak voltage delivered at the cavity bore to a matched 1.25-Ω load was specified to be $\geq$90% of the peak PFL output pulse. Output pulses with 1-MV peak voltage and durations of up to 55 ns were required. Electrode spacings within the cavity were selected so that the operational electric fields were 70% of the breakdown fields based on the area of twenty cavities. A similar requirement was used in designing the vacuum insulator stack.

Figure 1 is a photograph of the cavity mounted on STF for testing. The PFLs are connected to the cavity with 90° elbows. Polyurethane barriers separate the water in the PFLs and the oil in the cavity at these elbows. The cavity design incorporates azimuthal transmission lines to mix the input pulses from the four PFLs so that the interface between the oil-insulated cavity and the vacuum-insulated MITL is fed with four, nearly identical, pulses spaced 90° apart. This feature assures azimuthally uniform voltages are applied to the MITL adder independent of input jitter or differences in waveforms from the four PFLs. Figure 2 is a cut away drawing of the cavity showing the azimuthal lines and the oil/vacuum interface. Energy is alternately fed from the PFLs to the left azimuthal line then the right. Ninety degrees from the four feed points are four crossover points where energy is fed to the center azimuthal line. The azimuthal lines are arranged such that the transit times from each of the PFL feed points to an interface feed point are equal. Figure 3 is a schematic of the azimuthal transmission line circuit.

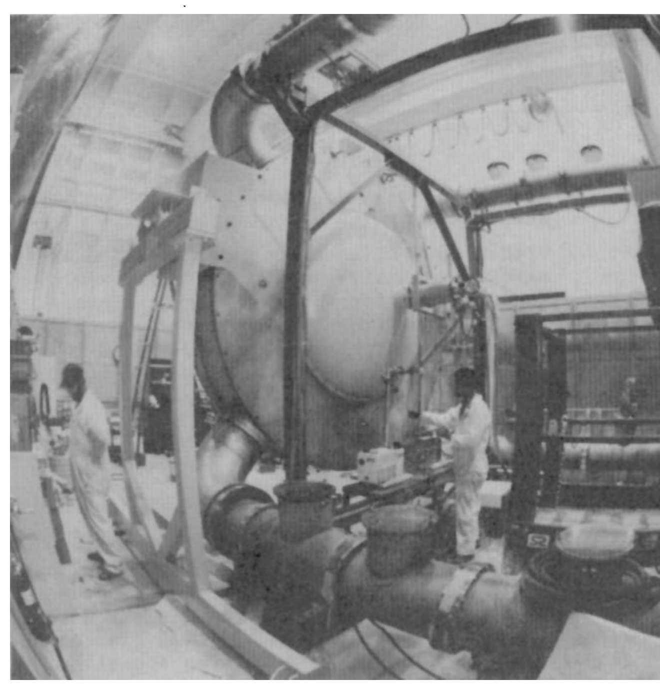

Fig. 1. Hermes prototype cavity mounted on STF

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14. ABSTRACT

The Hermes-III accelerator has twenty 1-MV, inductively isolated cavities connected in series through a high voltage, magnetically insulated transmission line (MITL) to produce a 20-MV, 800-kA pulse that drives a bremsstrahlung diode. Each cavity is 4 m in diameter and weighs nearly 8000 kg when filled with its insulating transformer oil. Cores of pre-annealed Metglas 2605CO are used to inductively isolate the cavities. Azimuthal transmission lines mix inputs from four pulse-forming lines; this reduces the effect of pulse-forming line jitter on the cavity output pulse. A single, prototype cavity has been tested on the System Test Facility (STF). The test results and comparisons with design specifications and circuit simulations are presented.

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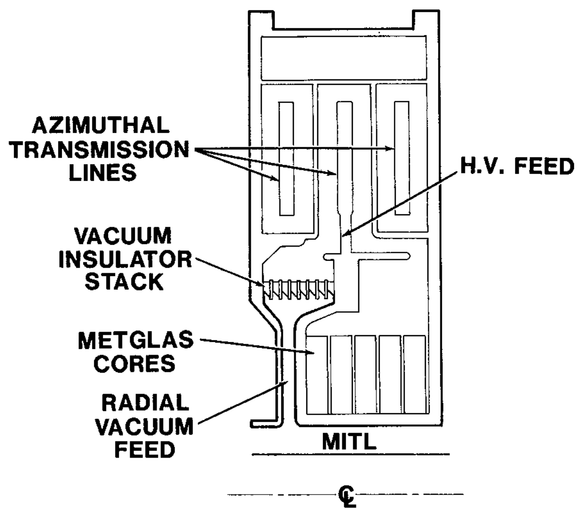

Fig. 2. Cut-away view of cavity

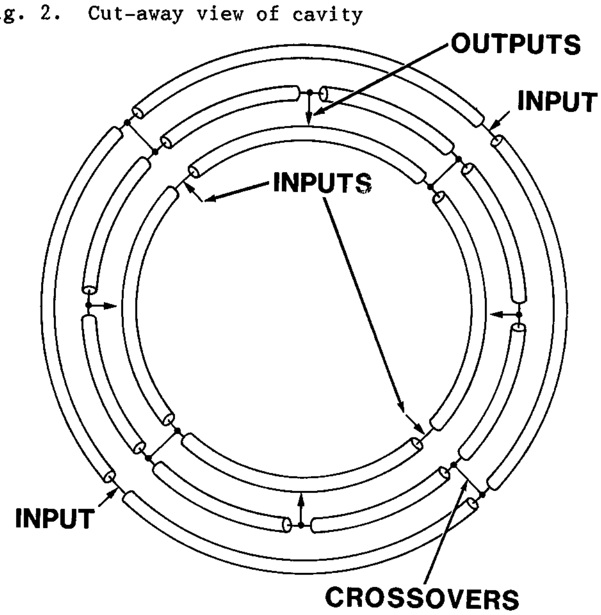

Fig. 3. Schematic of the cavity azimuthal transmission line network

An array of probes is used to monitor the performance of the cavities. Capacitive voltage monitors (V-dot) and current monitors (B-dot loops) are located on the outer azimuthal transmission lines and on the oil side of the vacuum insulator stack. A B-dot monitor is also used to monitor the current flowing through the cores, i.e., the loss current.

The cavity is evacuated using a vacuum roughing pump while back filling with transformer oil. This allows some impregnation of the cores as well as deaeration of the oil and elimination of trapped air. No oil recirculation for the cavity is planned.

A set of magnetic cores using Allied Corporation pre-annealed 2605CO Metglas is also shown in Fig. 2. The cores are required to withstand applied voltages of up to 1.5-MV peak with a volt·second product of 0.064.

Circuit Modeling

Circuit models of the cavity were used to evaluate and predict cavity performance. Figure 4 shows a single-line model used to analyze cavity performance with the SCREAMER[4] circuit code. The model was developed at PSI with the aid of low voltage pulse injection tests. Lossless transmission line elements were used to model the components within the cavity. The element impedance and delay length used were determined from the cavity geometry. A constant impedance load was selected that approximates the load of the MITL adder. Figure 5 is a PFL output pulse from STF that was used as an input to the code. Figure 6 is the output from the simulation and represents a zero jitter case. The pulse resulting from adding four of these pulses with a rms jitter of 3.5 ns (a first to last spread of ~7 ns) is shown in

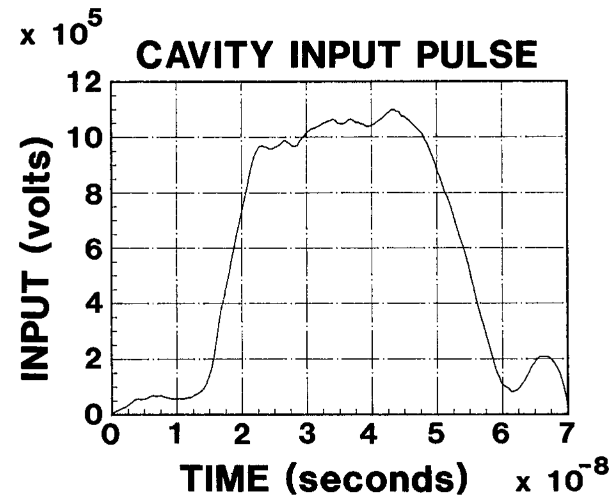

Fig. 5. PFL output pulse used as cavity input to the circuit model calculations

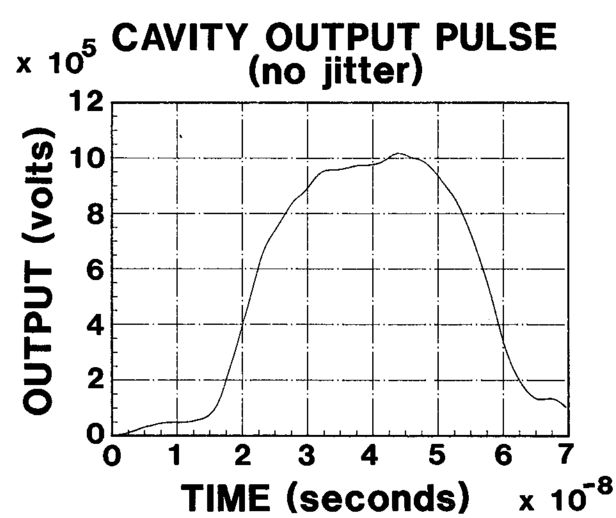

Fig. 6. Cavity output pulse from circuit model with no jitter

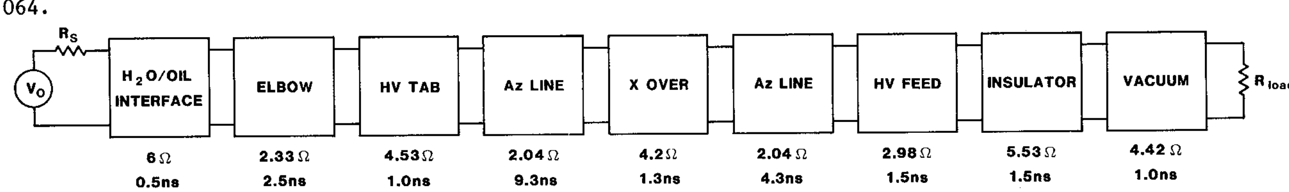

Fig. 4. SCREAMER circuit model of the cavity

Fig. 7. This pulse has a 17.5 ns, 10% to 90% rise time and meets the cavity requirements. The 3.5-ns value is used in this calculation instead of the 4.5 ns initially specified because it is representative of the jitter of the PFL modules developed in STF.[5]

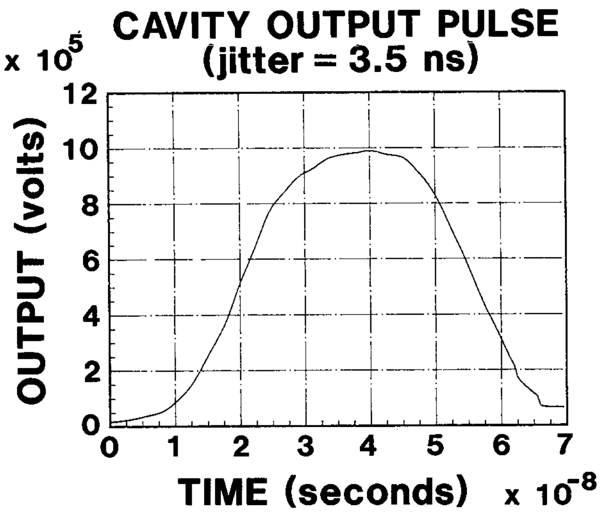

Fig. 7. Cavity output from simulation with 3.5-ns random jitter on the cavity input

STF Testing

Domes were added on the cavity (Fig. 1) to allow vacuum pumping of the bremsstrahlung diode used as the cavity load for these tests. The diode uses a sharp-edged emitter 38 cm in diameter as a cathode. Spacing this cathode 1.5 cm from the carbon anode results in a ~1.5-Ω electron beam load at peak power. Two levels of testing were done: one at the nominal 1-MV output, the second at a 25% overvoltage to account for the factor of 20 increase in cavity area for the full Hermes-III system (an area dependence[3] of $A^{0.075}$ was used in determining cavity oil breakdown levels). The cavity was also tested with the anode-cathode gap shorted in order to determine the diode inductance. A 7.5-nH inductance was measured with voltage and current monitors located on the oil side of the vacuum/oil interface; this compares favorably with the calculated inductance value of 7.2 nH.

An overlay of the cavity output pulse (measured across the vacuum insulator stack), one of the four PFL pulses, and the output current is shown in Fig. 8. The peak on the vacuum stack voltage is a result of the inductance and the initial high impedance of the diode. Two vacuum stack monitors located 180° apart yielded nearly identical waveshapes; this implies good mixing of the cavity input pulses. The first-to-last spread of the PFL switch times was 3.5 ns as determined by the PFL monitors for this shot. The 10% to 90% rise time of the current pulse is 15 ns, as compared to the input voltage rise time of 10 ns. Using the current monitor to determine the pulse rise time will result in an upper limit of the cavity response because of the diode turn-on time. The pulse amplitude degradation is difficult to assess, due to the voltage overshoot resulting also from the bremsstrahlung diode turn-on time. However, the voltage at the knee on the stack voltage is 1.2 MV, indicating a 1.5-Ω load impedance as compared to the 1.25-Ω PFL impedance. The inductive voltage component should be nearly zero and the diode impedance flat at this knee. Multiplying the 700-kA peak current times the approximate impedance of 1.5 Ω equals 1.05 MV, only a 5% reduction of the 1.1-MV peak input voltage. This, also, meets the cavity specifications.

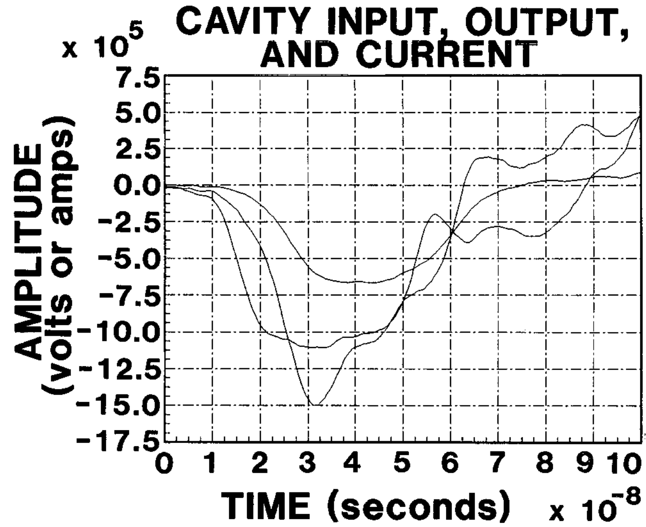

Fig. 8. Overlay of measured cavity input voltage, output (vacuum stack) voltage, and output diode current

The normal operation of the cavity is with the isolation cores set to their negative remanence, using a dc current source. From this starting point a volt·second product of 0.064 across the cores should be reached before saturation of the cores. The integral of the stack voltage (approximately the core voltage) is 0.050 volt·second for this shot and, as expected, no evidence of core saturation was seen under these conditions. To test the effect of core saturation, the cores were set to zero remanence by using an ac bias source and slowly reducing the current to zero. Saturation occurred for this case at 0.045 volt·second, as indicated by a sharp rise in the measured loss current. Since there is very little difference between the negative remanence point and the fully reversed bias point for these cores, the total volt·second for the cores should be nearly twice this saturation level or ~0.09 volt·second. More detailed information on testing of the Metglas cores is given by Huddle[6] elsewhere in these proceedings.

The prototype cavity was designed to use current contacts at most of the joints between conductors within the cavity to reduce or eliminate arcing. The cavity was assembled and tested without these contacts to determine if they are necessary. Following the testing of the cavity and cores on STF, the cavity was disassembled and inspected for damage. No evidence of arcing was found anywhere. As a result, the final cavity design for Hermes III does not use most of the current contacts. The cores, also, showed no evidence of arcing or carbonization.

During the testing some pitting of the anodized cathode surface in the vacuum feed was found. The anodization is used to reduce electron emission from the cathode. The pitting appeared to have originated from defects in the anodization. The surface was sanded and cleaned. Continued testing showed no further pitting. The vacuum insulators showed some slight surface tracking on the vacuum side. These insulators were initially assembled dry, without vacuum oil. After oiling the surfaces with a light coat of silicon vacuum oil, no further tracking was observed in subsequent tests.

Conclusion

The prototype cavity has been tested in STF and has been shown to exceed its specifications of 1-MV output with rise times less than 19 ns for a 1.1-MV, 10-ns input pulse; overvoltage tests imply that a full twenty-cavity system will be sufficiently reliable to

meet Hermes-III operational requirements. The two sets of cores tested, operated reliably and exceed the required volt·second product. Light surface tracks were observed on the vacuum insulator surfaces. Oiling the insulators eliminated these surface tracks.

Experience with the HELIA accelerator[7] indicates that the cavities can be operated for hundreds of shots over a period of several months before having to re-oil the insulators.

The Hermes-III cavity design is based on the prototype STF cavity and retains all of the essential electrical features of the prototype design. The majority of the changes were made to improve the manufacturability and reduce the cost. The changes were also aimed at improving the ease of assembly and handling of the cavities. Cavity components are presently being built. They will be pre-assembled, monitors installed and calibrated, and temporarily stored before beginning installation in November 1987.

References

1. J. J. Ramirez et al., "The Hermes-III Program," in Proceedings of the 6th IEEE Pulsed Power Conference, Arlington, Virginia, June 29-July 1, 1987.
2. R. C. Pate et al., "Self-Magnetically Insulated Transmission Line (MITL) System Design for the 20-Stage Hermes-III Accelerator," in Proceedings of the 6th IEEE Pulsed Power Conference, Arlington, Virginia, June 29-July 1, 1987.
3. L. Schlitt, W. Weseloh, I. Smith, V. Bailey, D. Garofalo, and D. Battilana, "Hermes-III Induction Cavity Design," PSI Report No. PSI-FR-234-3, July 1986.
4. M. L. Kiefer and M. M. Widner, "SCREAMER--A Single-Line Pulsed Power Design Tool," in Proceedings of the 5th IEEE Pulsed Power Conference, 1985, pp. 685-688.
5. J. P. Corley et al., "Development and Testing of the Hermes-III Pulse Forming Transmission Lines," in Proceedings of the 6th IEEE Pulsed Power Conference, Arlington, Virginia, June 29-July 1, 1987.
6. C. W. Huddle, D. L. Johnson, G. J. Denison, and T. L. Franklin, "Testing of the Inductive Cores for Hermes III," in Proceedings of the 6th IEEE Pulsed Power Conference, Arlington, Virginia, June 29-July 1, 1987.
7. J. J. Ramirez et al., "The Four-Stage HELIA Experiment," in Proceedings of the 5th IEEE Pulsed Power Conference, 1985, pp. 143-146.